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PRELIMINARY RESULTS, SUMMER STUDY  
OF THE  
HUDOCKS PROTECTIVE SHELTER

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**PRELIMINARY RESULTS, SUMMER STUDY OF THE  
BUDOCKS PROTECTIVE SHELTER**

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On 15 August 1962 the summer habitability test of the Bureau of Yards and Docks protective shelter located at the Naval Medical Center, Bethesda, Maryland was completed. After a two-week stay in the shelter, 99 Navy men emerged from the shelter in satisfactory physical condition. LTJG John T. White, CEC, USN was Shelter Commander. Captain David Minard, MC, USN and three Navy corpsmen constituted the medical staff. John T. Mullen, EOCA, USN\* and Kenneth Evans, EUL, USN were section leaders. Paul Gosseln, PHAN, USN from the Naval Photographic Center, Washington, D. C. was assigned as photographer. The remainder of the volunteer subjects were recent graduates of the Navy Recruit Training Center, Great Lakes, Illinois, clinically describable as "normal, healthy young males."

The purpose of the test was to evaluate, under actual operating conditions, the shelter techniques developed by the Bureau of Yards and Docks over a period since World War II. The shelter is the standard Bureau of Yards and Docks ammunition magazine type corrugated steel shelter, 48 ft. long, with a 25 ft. arch span, buried under five feet of earth cover. A 12 ft. x 14 ft. space is taken up by biological and chemical warfare protection facilities. In this area a 600 cfm collective protector is installed and space is provided for biological, chemical and radiological personnel decontamination. For this test, because of the high outside temperatures expected, a 1200 cfm blower was substituted. Further, air conditioning was installed to provide mechanical cooling if it were required to prevent aborting the test. Under the conditions of outside temperature and humidity which prevailed, this equipment was not needed, but it was exercised during the last 29 hours of the test. The structure is reinforced for 75 p.s.i. blast overpressure and appropriate blast closure devices are provided for entranceways and air ducts.

The Bureau of Yards and Docks requested the Naval Research Laboratory and the Bureau of Medicine and Surgery and its Naval Medical Research Institute to perform the study, and established objectives for the tests designed to provide data for design improvement. The author was BuDocks "Project Manager" in the test. A two-week cold weather test was conducted starting February 17, 1962. A more detailed description of the winter test has appeared in a previous article.\*\* The summer test was designed to obtain data peculiar to summer operating conditions. As was the case in the winter test, observations were made in several technical areas. Overall technical control was in the hands of

\* An article concerning Chief Mullen and describing his experiences in the BuDocks Shelter is to appear in the next issue of the "Navy Civil Engineer."

\*\* "Shelter Tests Produce Important Design Data" by CDR E. M. Saunders, Navy Civil Engineer, May 1962

Dr. Eugene A. Ramskill, Naval Research Laboratory. Mr. Harold F. Bogardus, NRL, collected data on atmospheric characteristics and temperatures within the shelter. Dr. Ramskill and Mr. Bogardus have done basic work in nuclear submarine habitability. Dr. Minard, attached to the Naval Medical Research Institute, performed physiological studies on the subjects. These studies were principally concerned with heat stress, an area in which Dr. Minard is a universally accepted authority. Dr. John Rasmussen, NMRI, studied psychological factors. Dr. Robert Van Reen evaluated the effects of the diet. Studies were also made of bacterial flora, and general medical and dental problems.

This article presents a review of the limited data which was available and evaluated a few weeks after the conclusion of the test and reaches some preliminary conclusions. An NRL report will be issued in early 1963, giving a detailed account of the summer study. A report of the winter test is in the final stages and will appear shortly.

During the first 4½ hours of occupancy, the shelter was in a buttoned-up condition. Atmospheric conditions approached the following: O<sub>2</sub> - 18%; CO - 60 ppm; CO<sub>2</sub> - 3%. Shortly after starting the ventilation blower at the rate of 300 cfm, atmospheric conditions were as follows: O<sub>2</sub> - greater than 20%; CO - 10-20 ppm; CO<sub>2</sub> - less than .5%. Typical values for these quantities throughout the remainder of the test were not below these levels of quality. Limiting values for nuclear submarines are as follows: O<sub>2</sub> - 19%; CO - 50 ppm; CO<sub>2</sub> - 1%.

Odors were never a problem to the occupants of the shelter nor were they offensive to observers who entered the shelter entrance tunnel frequently throughout the test (without being seen by the occupants). Smoking was permitted without restriction for the last hour of the buttoned-up period and thereafter. Smoking did not constitute an appreciable irritation, even to non-smokers. Sound levels ranged between 65 and 85 db, which permitted face-to-face conversation but made group communications impossible without voice amplification equipment.

The 10 kw generator operated on a normal load of 4 kw satisfactorily throughout the test except for a period of one hour when there was an air leak in a fuel system suction line. This condition was repaired by the shelter occupants. The engine ran at a cooling water temperature of 170°F. Temperatures in the entrance passageway, where the generator is located, ranged between 105 and 122°F.

As in the previous test, only three of the six installed chemical toilets were utilized. An organic iodine compound (containing 1.75% available iodine) was used to deodorize and help liquify the sewage which was periodically drained to a dry-well located outside the shelter. This system operated satisfactorily. During the test, approximately 425 cubic feet of trash were accumulated.

The diet consisted of two meals with a total of 1850 calories. The basic staple was a survival ration cracker developed for the State of New York. One meal consisted of 26 crackers, 20 grams of jam or jelly, 2 packets each of powdered coffee, powdered cream and sugar. The other meal consisted of 26 crackers, 16 grams of peanut butter, 6 ounces of hot soup and one packet each of coffee, cream and sugar. The volunteers accepted the diet much more readily than in the winter test. During and following the test there was little active complaint about the food. However, the average weight loss was a few pounds greater than the approximate five pounds average of the winter test. It is not known at this time whether this weight loss was predominantly due to dehydration or loss of body tissue.

Psychological questionnaires were completed during the test and the volunteers were interviewed by a team of psychiatrists and psychologists at the completion of the test. Table I lists the five most irritating factors in the opinion of the volunteers for both the winter test and the summer test. It is interesting to note that temperature and humidity were least significant of the discomfort factors measured in the winter test, but ranked next to most significant in the summer test. As in the winter test there were few psychological problems, no doubt due to the fact that the volunteers were carefully screened to exclude possible psychological problems. An exception, was one staff member who did not undergo the initial screening. He was removed on the second day of the test at his own request. It is interesting to note that money was valueless in the shelter society and that the "wet packet napkins" containing moist paper washcloths were used as a medium of exchange. One man succeeded in amassing a "fortune" of approximately 100 "wet packet napkins."

The 1 August date was chosen some months in advance and it was hoped that Washington would experience a normal, hot summer. However, it developed that July 1962 was the coldest July in Washington since 1924. The weather during the first two weeks of August was warmer than July, but fell somewhat short of the investigators' hopes. Table II tabulates the weather conditions near the shelter during the period of the test. Almost exactly halfway through the test, the weather changed from warm to cool, the maximum dry bulb temperatures in the first week running between 88 and 92° (except for one day at 81°) and during the second week, they ran 78 - 86° (except for one day at 73.5°). The ventilation rate inside the shelter was 300 cfm for the first two days, 600 cfm for the remainder of the first week, and starting as an unintentional coincidence with the break in weather, 1200 cfm for the second week. In order to achieve the 1200 cfm, it was necessary to reduce back pressure by opening the blast door.

The dry bulb temperature taken inside the shelter near the air exhaust, during the period from the end of the second day to the end of the seventh day, varied within the relatively narrow limits of 87° to 91.8° with a maximum variation in any one day of 2 degrees. During the second week the maximum variation in any one day of dry bulb temperature was 4°.

and that on a day when the outside dry bulb temperature varied by almost 30 degrees. In fact, during the last 12 days of the test, the limits of the dry bulb temperature were 86° - 91.3°, a spread of only six degrees. On the other hand, during this same period, the wet bulb temperature within the shelter varied over the considerably larger range of 70° - 83°. These data raise the question of whether the occupants of a shelter are capable of moderating the amount of sensible heat at the expense of latent heat of vaporization.

The effective temperature\* within the shelter rose during the first two days to a maximum of about 87°F. On the third day it dropped to about 84° and rose on the seventh day to about 87° average. During the last week the effective temperature fluctuated between 84° and 80°. These effective temperature readings are based on a preliminary review of the data and will undoubtedly be refined in the final report.

Although effective temperatures within the shelter during the first week frequently exceeded 85°, only minimal specific signs of physiological strain resulting from heat stress, such as elevated body temperature or accelerated pulse rate, were observed. Non-specific signs of strain from heat stress, such as loss of appetite and loss of sleep became evident during the first week. Moreover, two cases of heat exhaustion occurred near the beginning of day seven. These were characterized by weakness and faintness. One case exhibited hyperventilation followed by unconsciousness and periodic breathing. This case was removed from the shelter and rapidly recovered. The second case was treated within the shelter with intravenous injections of fluid and nourishment. He, too, recovered quickly. In the opinion of the medical officer, additional cases of heat exhaustion would have resulted had there not been a reduction in the effective temperature. On the beginning of day eight, the ventilation rate was increased to 1200 cfm. Almost simultaneously the weather changed, as shown by Table II, and the two effects combined to reduce the effective temperature from approximately 87° on day seven to about 80° on day nine.

Water consumption during the winter test was about 1½ quarts per man per day. During this test water consumption was about three quarts per day, somewhat less than expected based on a predicted effective temperature of 85°. However, the water consumption observed reasonably coincides with that calculated from the so-called "predicted 4-hour sweat rate," based on dry bulb temperature, wet bulb temperature, clothing and metabolic rate. Water consumption was also

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\*Effective temperature is a measure of apparent temperature felt by the human body. It is normally found by using a chart form in the ASHVE Handbook and may be approximated by the so-called Thom scale:  $0.4 (\text{dry bulb temperature} + \text{wet bulb temperature}) + 15^\circ\text{F}.$

consistent with some previous work of the Naval Medical Research Institute which correlated water needs with dry bulb temperature alone. Figure 1 shows predicted perspiration water needs as a function of dry bulb temperature.

Since this shelter is provided with only 50 bunks, shelter operating schedules necessitated alternate bunk time for each section of 50 men. Three schedules were used during this test:

- A. 8 hours bunk time; 16 hours activity time for each section.
- B. 8 hours bunk time; 8 hours activity time; 4 hour bunk time; 4 hours activity time for each section.
- C. 9 hours bunk time; 15 hours activity time for each section.

Schedule A was used for 4 days and was the same as that schedule used during the winter test. Schedule B was also used for 4 days and provided the lowest level of activity (50 men in bunks at all times). Schedule C was used for the last 7 days. This schedule provided a period of six hours when all men were up.

During the test, the occupants were extremely inactive, spending the maximum available time in bed. Heat calculations involving human body heat usually assume 400 BTU/hour or 100 Kcalories/hour given off by the human body at rest. However, this group was extremely inactive, and they were asleep during a large part of the time. Hence, a smaller heat output, say in the range of 75 to 80 Kcalories/hour, is indicated.

The medical team was kept busy during this test. On the fifth day 29 of 46 men in one section appeared at sick call. Infections of the upper respiratory tract (i.e., colds) were common. There were 8 to 12 cases of bronchitis. Pneumonia, though feared, did not develop. One subject demonstrated many of the symptoms of acute appendicitis and was released from the shelter for one hour for detailed laboratory tests which were negative. Heat rash was widespread. Aside from a number of secondary infections of heat rash, there was no evidence that the inability to bathe contributed to health problems within the shelter. Although fungus infections were anticipated, few developed. These were controlled by foot hygiene involving daily application of fungicidal foot powders.

Some preliminary conclusions can be reached from the data available to date:

- (1) Normal, healthy young males can survive under about 87° effective temperature for a period of seven days with only a small percentage becoming incapacitated by heat. No assurance can be found in the data of this test that such a level can be maintained for as long as fourteen days.

(2) A ventilation rate of 600 cfm is inadequate for this shelter. In this test, at this air flow rate, a 2% casualty rate was reached within one-half of the design operating period.

(3) Effective temperature appears to be a valid measure of human physiological response to heat in shelters, but cannot be used to forecast water needs. The predicted "4-hour sweat rate" and dry bulb temperature are better indicators of water requirements.

(4) Because of the rapid spread of infectious diseases, medical problems become of great importance. The presence of trained medical personnel served to minimize health problems. The nature of diseases observed with this group of individuals did not constitute a serious medical hazard; however, other more serious diseases might have occurred in a less homogeneous population.

(5) A diet consisting of 1850 calories per day is adequate to maintain operational capability of the shelter occupants.

(6) Adequate floor space is included in the shelter. Providing bunks for 50% of the occupants presents an insignificant operational problem, conserves space and reduces expense. Three toilets are adequate for this 100 man shelter.

TABLE I

MOST IRRITATING DISCOMFORT FACTORS RESULTING  
FROM THE BUDOCKS SHELTER TESTS

<u>Winter Test</u>	<u>Summer Test</u>
1. Food	1. Lack of Water for Washing
2. Lack of Water for Washing	2. Temperature and Humidity
3. Crowding	3. Dirt
4. Dirt	4. Food
5. Behavior of Others	5. Crowding

Note: There were 21 discomfort factors measured during these tests, but only the 5 most irritating are listed here. It is interesting to note that a study of the statistical spread of discomfort factors revealed the top two factors for the Winter Test were significantly more irritating than the others listed, but that both of them had almost the same degree of irritation. Such a statistical study has not yet been made of the summer data.



Caption for Table II

This table gives maximum shelter temperatures and ambient conditions near the shelter during the test. Effective temperatures follow the ASHVE Handbook. Wet bulb temperatures on which the effective temperatures are based were taken simultaneously with the dry bulb temperatures. The effective temperatures for the shelter interior are subject to refinement in the process of data evaluation.

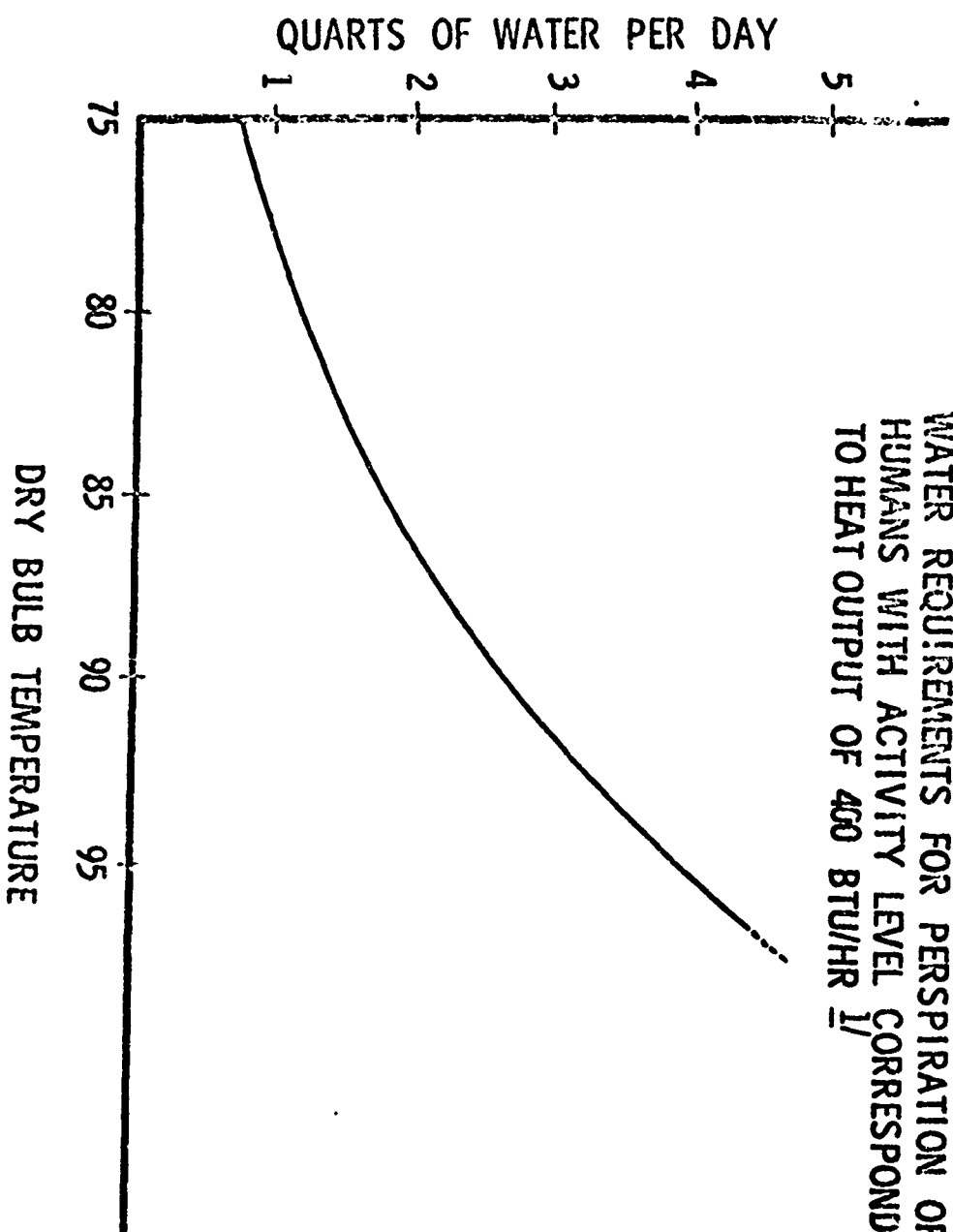
Interior shelter temperatures are dependent on ventilation rates. From 1100 to 1530 1 August there was no ventilation. At 0830, 3 August ventilation was raised from 300 to 600 cfm. At 1300, 3 August the ventilation was increased to 1200 until the end of the test. In addition, air conditioning up to a maximum of 6 tons was also introduced on the last two days.

TABLE II  
EXTERIOR WEATHER CONDITIONS AND SHELTER EFFECTIVE TEMPERATURES  
DURING THE SUMMER TEST

<u>Date</u>	<u>Ambient</u>		<u>Ambient</u>		<u>Shelter</u>	
	<u>DB(Max)</u>	<u>ET</u>	<u>DB(Min)</u>	<u>ET</u>	<u>DB(Max)</u>	<u>ET</u>
8/1	85	76.0	70	68.5	87	85.0
8/2	88	73.0	82	75.8	90	87.2
8/3	88	83.8	75	71.0	90	87.0
8/4	81	75.3	70.5	68.8	90	86.2
8/5	89	81.6	72	70.7	92	89.1
8/6	90.5	82.6	74.5	72.8	91	87.5
8/7	88	81.7	74.5	73.0	92	87.2
8/8	92	81.3	63	67.0	91	85.1
8/9	79.5	74.5	68	67.6	89	82.1
8/10	73.5	70.0	63.5	62.5	87	82.2
8/11	73	73.0	60	59.5	89	80.0
8/12	36	77.0	57.5	57.0	90	82.1
8/13	82	77.0	64	63.0	90	83.7
8/14	86	77.0	69	63.4	88.5	82.2
8/15	72	68.4	60.5	59.5	85.5	78.2

FIGURE 1

WATER REQUIREMENTS FOR PERSPIRATION OF  
HUMANS WITH ACTIVITY LEVEL CORRESPONDING  
TO HEAT OUTPUT OF 460 BTU/HR 1/



1/ KELLOGG, RALPH H. - "Critical Factors in Minimai Air Cooling  
of Living Quarters" NMRI Project X-205,  
Report No. 7, 26 November 1946.